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Anxiety symptoms of major depression associated with increased willingness to exert cognitive, but not physical effort

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Abstract

Reduced cognitive function in major depression (MDD) is often interpreted as a reduced ability to exert cognitive control. Here we used the Effort Foraging Task to test the hypothesis that reduced cognitive function may be due, in part, to decreased willingness to exert control in MDD because of increased cognitive effort "costs". Contrary to our predictions, neither cognitive nor physical effort costs differed with MDD diagnosis (N MDD=52, N Comparisons=27). However, we found distinct patterns of symptom relationships for cognitive and physical effort costs. In MDD, greater anxiety symptoms were selectively associated with *lower* cognitive, but not physical effort cost (i.e. greater willingness to exert cognitive effort), whereas greater anhedonia and behavioral apathy symptoms were selectively associated with increased physical (but not cognitive) effort costs. These findings support the measurement of both cognitive and physical effort as decision-making function markers that may inform heterogeneity of MDD.

Keywords: cognitive neuroscience; decision making; mood; bayesian modeling; clinical methods

Introduction

Individuals with major depression (MDD) can experience challenges with goal-directed behavior, including reduced motivation due to symptoms such as apathy and anhedonia, and reduced cognitive function (e.g., difficulty concentrating, switching between tasks, holding things in mind). Cognitive function challenges in depression contribute to disability (Jaeger et al., 2006) and are often not improved with otherwise effective anti-depressant treatments (Halahakoon & Roiser, 2016; Rosenblat et al., 2016). Grahek and colleagues (2019) proposed a connection between reduced motivation and reduced cognitive function, challenging the standard understanding that reduced cognitive function reflects reduced cognitive control capacity (Millan et al., 2012; Rock et al., 2014; Snyder, 2013). By this account, reduced cognitive function associated with MDD may be, in part, because of reduced willingness to exert cognitive effort. Willingness to exert cognitive effort can be understood in terms of costs and benefits, in which people maximize the 'expected value' of effort by selecting actions that maximize potential reward while minimizing required effort (Rigoux & Guigon, 2012; Salamone et al., 2018; Shenhav et al., 2013, 2017; Walton et al., 2007). Resolving these accounts has implications for treatment of cognitive function challenges in MDD. By the cognitive effort decision making account, interventions to improve cognitive function would focus on boosting motivation and target willingness to engage control, rather than cognitive control ability (e.g., computerized cognitive training) suggested by the reduced capacity account.

MDD has been associated with decreased willingness to exert cognitive effort relative to comparison groups in some studies (Ang et al., 2023; Vinckier et al., 2022; Westbrook et al., 2022) though not in others (Barch et al., 2023; Tran et al., 2021). Similarly, some studies show associations with clinical features of MDD (i.e., global functioning Tran et al., 2021; Westbrook et al., 2022) while others do not (e.g., not related to depression, anhedonia, apathy Ang et al., 2023; Barch et al., 2023; Hershenberg et al., 2016; Vinckier et al., 2022). MDD heterogeneity may contribute to inconsistent findings with respect to diagnostic group differences and associations with clinical features of MDD (including symptom strength). For example, findings may vary depending on the prevalence of reduced motivation in MDD samples, since reduced motivation symptoms (i.e., apathy and anhedonia) vary across individuals and are absent in some individuals with MDD (Ang et al., 2017; Nakonezny et al., 2010).

Willingness to exert physical effort has been found to be decreased in MDD (Berwian et al., 2020; Cléry-Melin et al., 2011; Treadway, Bossaller, et al., 2012; Vinckier et al., 2022; Wang et al., 2022; X.-H. Yang et al., 2014; Zou et al., 2020). Though findings have been mixed, with some studies not showing differences between MDD and comparison groups for physical-effort decision making (Cathomas et al., 2021; Sherdell et al., 2012; Tran et al., 2021; Wang et al., 2022; X. Yang et al., 2021). Similarly, relationships between physical effort avoidance and depression symptom strength have been inconsistent across existing studies, with some studies showing associations with MDD symptoms (Sherdell et al., 2012; Tran et al., 2021; X.-H. Yang et al., 2014, i.e., anhedonia) and others not (e.g., not related to depression, apathy, anhedonia, Berwian et al., 2020; Cathomas et al., 2021; Cléry-Melin et al., 2011; Vinckier et al., 2022; Wang et al., 2022; X. Yang et al., 2021; Zou et al., 2020).

There are also other symptoms of depression, such as anxiety which may have differential relationships to effort. Anxiety symptoms such as rumination (e.g., replay) and worry (e.g., planning) may require cognitive effort (e.g., sampling Bedder et al., 2023), and anxiety symptoms have been related to increased effortful model-based planning (Gillan et al., 2016; Hunter et al., 2018). An implication could be that

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reduced cognitive function may be more prevalent in individuals with MDD without co-morbid anxiety, than those with co-morbid anxiety. Anxiety is the most common comorbidity with depression (Kessler et al., 1996) but the prevalence may vary across study samples. It therefore may be important to account for this heterogeneity and relate cognitive effort decision making to specific depression symptom expression profiles (or subtypes), as some have suggested (Lynch et al., 2020).

Taken together, both cognitive and physical effort avoidance appear to be associated with features of MDD, suggesting effort-based decision-making processes may underlie certain MDD symptoms. It remains unclear which symptoms map onto which component decision processes, and how shared or distinct these mappings are between cognitive and physical effort. To resolve this, studies need to measure the relative contribution of cognitive and physical effort-based decision making to symptoms within individuals. Initial studies doing this found differential relationships of cognitive and physical effort decisions to symptoms (Tran et al., 2021; Vinckier et al., 2022). This raises the possibility that mechanistically informed measures of cognitive and physical effort decisions combined with symptom expression profiles may be useful in characterizing MDD heterogeneity.

In the present study we used the Effort Foraging Task (Bustamante et al., 2023) which embeds cognitive or physical effort into a patch foraging decision-making task. We hypothesized that some of the inconsistencies with MDD symptom relationships in the cognitive and physical effort literature may have to do with methodological limitations of the previously used tasks. Most previous studies used a direct choice style in which participants choose between low effort/low reward and high effort/high reward options. This direct choice style may bias decisions due to demand characteristics which cue participants to the purpose of the study and change how participants behave (Orne, 1962) and this effect can be idiosyncratic across individuals (e.g., impress the experimenter, engage negative self-image). The Effort Foraging Task task was designed to minimize demand characteristics by estimated effort avoidance indirectly based on the effect of effort on foraging behavior.

Methods

Participants

97 participants volunteered for the study (67 MDD, mean=26.9 years, SD=11.1, 18-61 years; 30 comparison mean=27.1 years, SD=9.64, 19-59 years). In the first session participants completed the structured clinical interview (N=67 MDD, 30 non-psychiatric comparisons). In the second session participants completed the Effort Foraging Task (N=60 MDD, 27 comparison). Only the participants who completed the first and second session were included in the symptom severity analyses. Of these, 45 MDD participants were currently depressed, 12 MDD participants were partially remitted, and 3 were remitted depressed, 32 MDD participants took psychoactive medication while 28 did not.

Symptom measures

The SCID-5 was used to confirm assignment of MDD and comparison participants met study diagnostic criteria. Based on responses in the SCID-5 the clinical interviewer completed the Hamilton Rating Scale for Depression measure of the strength of different symptoms in the past week (Hamilton, 1960). Since this is the standard measure of MDD severity, we used the total score to assess general severity relationships (herein referred to as ’overall depression’). In order to further decompose severity relationships, we collected additional clinician-rated and self-report measures in order to capture different domains of symptoms. We performed confirmatory factor analysis to create composite scores for the symptoms: anhedonia, anxiety, behavioral apathy, emotional apathy, social apathy, cognitive function symptoms, depressed mood/suicidality, and physical anergia/slowing. For each confirmatory factor, assigned items were Z-scored and averaged to compute a symptom score in the MDD group only. We measured the internal consistency using Cronbach’s alpha (ltm package cronbach.alpha function, Rizopoulos, 2006), factors with alpha below 0.6 were eliminated (emotional apathy, and appetite symptoms). We inspected the inter-item correlations using (multilevel package, item.total function, Bliese et al., 2022), items with inter-item correlation below 0.2 were eliminated. Items were drawn from the following measures: the Brief Psychiatric Rating Scale (Overall & Gorham, 1962), the MGH Cognitive and Physical Functioning Questionnaire (Fava et al., 2009), the Patient Heath Questionnaire-9 (Kroenke et al., 2001), the Generalized Anxiety Disorder-7 (Spitzer et al., 2006), the Snaith–Hamilton Pleasure Scale (Nakonezny et al., 2010), the Apathy Motivation Index (Ang et al., 2017). We confirmed the MDD group was higher on all symptoms except emotional apathy, which was not used.

Effort Foraging Task

In the Effort Foraging Task participants harvested apples in virtual orchards, which were converted to money as a bonus payment (up to $10, Figure 1, complete methods described in Experiment 2 of Bustamante et al., 2023). On each foraging trial the participant visits a ‘patch’ which can be harvested to yield rewards. Within a given patch, the marginal return (apples) associated with each successive harvest decreases over time. At any point the participant can travel to a new patch, which has replenished rewards, but it takes time and either cognitive or physical effort to travel there. Deciding when to leave a depleting patch involves tradeoffs between harvesting rewards available from the current patch, and the time and effort cost spent traveling to a different (but richer) one. Patches were presented block-wise, blocks varied only in effort travel task. Cognitive effort conditions required completing the N-Back working memory task (1-Back and 3-Back levels, , Nystrom et al., 2000). Physical effort conditions required completing rapid key presses with the non-dominant pinky finger (50% or 100% of an individually calibrated maximum, commonly used as manipulation of physical effort in MDD studies, e.g., Berwian et al., 2020; Tran et al., 2021; Treadway, Bossaller, et al., 2012; Treadway et al., 2009; Wang et al., 2022; X.-H. Yang et al., 2014; X. Yang et al., 2021). All other aspects of the foraging environment were fixed (7 minutes per block, 2 blocks per travel task per effort type, 8 blocks total, 2 second harvest time, 20 second travel time, starting reward=$N(15,1)$, mean depletion rate=0.88*previous harvest value). The reward value at which the participant decides to exit the current patch (i.e., their 'exit threshold' or the number of apples they have last received before leaving) reflects the reward they are willing to forgo by leaving that patch and spending the time and effort to travel to another. In these respects, the exit threshold reveals the point of equivalence in the tradeoff between the cost of harvesting with diminishing rewards and the cost of traveling to a new patch. Therefore, the longer a participant delayed leaving the patch (i.e., the lower the exit threshold) in the high versus low effort condition the larger their inferred effort avoidance. Reaching a new patch was not dependent on task performance. Participants had to reach performance criterion during training to begin the foraging task.

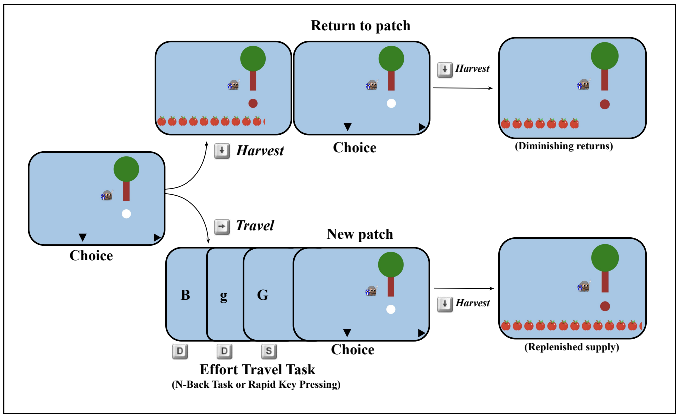

Figure 1: Effort Foraging Task Diagram. On each trial participants chose to harvest a virtual patch (apple tree) using the down arrow key, or travel to a new patch. Harvesting a patch yielded diminishing returns, whereas traveling to a new patch cost time and effort. Travel tasks were either the 1-Back or 3-Back levels of the N-Back task, or a smaller or larger number of rapid keypresses.

Marginal Value Theorem (MVT) model

We used a computational model to infer the cost of the cognitive and physical effort given the change in exit threshold from high to low effort travel conditions. Effort costs were estimated using a Hierarchical Bayesian logistic regression model based on the Marginal Value Theorem (MVT) to predict participants' choices to harvest or exit a patch by comparing expected reward on the next harvest against the average reward rate (described in full in Bustamante et al., 2023). According to the MVT, a foraging agent should leave a patch when instantaneous reward rate falls below the long run average reward rate (Charnov, 1976; Constantino & Daw, 2015). Therefore, decisions to leave the patch reveal perceived environmental quality.

MVT exit thresholds (ρ) were taken as fixed per-condition, determined by the total rewards ($\sum r$), total amount of time (number of harvest periods, T=condition duration/harvest time) and total travel costs ($\sum c$, sum over total times travelled in a condition) across all blocks of a condition. We estimated travel costs in the low and high effort conditions by predicting harvest versus exit decisions using a hierarchical Bayesian logistic model (equation 2). For each trial, model compares the expected reward on the next harvest (R_e, defined as the average of the previous harvest and the product of the previous harvest with the mean depletion rate (0.88)) against the exit threshold for a condition type (ρ) using a softmax function (with inverse temperature parameter, β) to make a choice (harvest or exit). The cost of travel in high effort blocks ($c_{\text{high effort}}$) was expressed as the marginal increase in cost of travel ($c_{\text{low effort}} + c_{\text{high effort}}$) from low to high effort. Defining this cost as a difference measure controls for any additional biases individual participants may have which are common to both conditions (i.e., consistently high exit thresholds for some participants and low thresholds for others). We used ($c_{\text{high effort}}$) as the dependent measure of the effort cost for an individual. For each effort level (low and high) and effort type (cognitive and physical) we predicted choices to stay or exit a patch:

$$P(stay_{\text{condition}}) = \frac{1}{1+\exp\left(\beta(R_e - \rho_{\text{condition}})\right)}, \tag{1}$$

where,

$$\rho_{\text{condition}} = \frac{\sum r - \sum c_{\text{condition}}}{T_{\text{condition}}} \tag{2}$$

Individual participant parameters and their group-level distributions were estimated using Markov Chain Monte Carlo sampling, implemented in Stan with the CmdStanR package 4,000 samples, 2,000 warm-up samples, across 4 chains, Stan Development Team, Stan, 2021. The prior distributions for group-level effects were $c_{\text{low effort}} \sim \mathcal{N}(0,25)$, $c_{\text{high effort}} \sim \mathcal{N}(0,15)$, $\beta \sim \mathcal{N}(0,1)$. The prior on random effects variances were $c_{\text{low effort}} \sim \mathcal{N}(0,25)$, $c_{\text{high effort}} \sim \mathcal{N}(0,15)$, $\beta \sim \mathcal{N}(0,1)$.

Symptom associations with effort costs To test for diagnostic group differences, we used linear regression to predict cognitive or physical effort costs by diagnostic group, controlling for high effort task performance, years of education, age, and BMI (for physical effort) (using the lme4 package Bates et al., 2022 in the R language). Within the MDD group, we ran a series of linear regression models to test for symptom severity effects on cognitive and physical effort costs. First, we predicted cognitive or physical effort costs from overall depression severity (i.e., Hamilton Rating Scale for Depression total) using linear regression. Next, we decomposed overall depression effects into specific symptoms. We predicted effort costs from each symptom domain separately in a series of regression models (z-scored, 7 tests for each effort cost). Because of mutual correlations between symptoms, we used multiple comparisons correction within a series of symptom models (FDR, 7 tests). Cognitive effort cost regressions controlled for cognitive task performance (3-Back D'), and age. Physical effort cost regressions controlled for physical task performance (% larger number of presses completed), age, and self-reported body mass index. Therefore, any symptom associations detected are over and above effects of travel task ability.

Results

We confirmed that the diagnostic groups were matched on gender, race, age, parental education, total household income, childhood income, and years of education for mother and father (using chi-square tests for categorical or t-tests for continuous variables, R stats package "R: The R Stats Package", n.d.). The comparison group had more years of education than the MDD group (t=-2.51, df=47.7, p<0.016).

Of the 60 MDD and 27 comparison participants, 1 MDD participant did not complete the effort foraging task due to technical difficulties with their keyboard. All other participants completed the Effort Foraging Task, however technical difficulties with the experiment server caused 4 missing data files from the MDD group. We followed a subset of exclusions validated in Bustamante et al. (2023) that most interfere with estimating effort costs. First, participants were excluded if they had very few exit trials within an effort type, making their data under-powered for estimating exit thresholds, and overly deterministic for logistic regression, which are the basis of the effort cost measures (2*SD below the mean, <8.82 trials). As a result 1 MDD participant was excluded for the whole task (1 exit in high effort physical and 3 exits in high effort cognitive condition) and 1 MDD participant was excluded from the cognitive effort analyses (2 exits for the cognitive high effort condition). Second, participants were excluded from the task if they missed the response deadline on many foraging trials (2*SD above the mean, >15.05%, 1 MDD participant excluded who missed 49.5%) which may reflect low engagement with the task or challenges meeting the response deadline. Ultimately, this affects the interpretability of MVT estimates (e.g., experienced harvest time longer than for other participants, fewer apples per second). The final sample included in behavioral analyses was 52 MDD participants (53 MDD participants in the physical effort condition) and 27 comparison participants. We confirmed the diagnostic groups were still demographically matched for participants included in task-based analyses.

Sensitivity to effort manipulation The MVT model group-level posterior parameters indicated high effort cost is greater than zero for both effort types (cognitive estimate=14.8 apples, p<0.001, physical estimate=15.2, p<0.001), and cognitive and physical effort costs were not correlated in this sample (p>0.461) consistent with Experiment 2 of Bustamante et al. 2023. There was considerable individual variation in willingness to exert effort, signaling differences in perceived effort costs (Figure 2). For all following analyses we extracted these participant-level effects and used frequentist analyses so that we could control for a range of variables and conduct multiple comparison corrections. We conducted a posterior predictive check and found that the observed probability of harvesting (across all participants and all foraging trials) fell within the posterior predictive distribution (p>0.589) suggesting the model was able to capture foraging choices. We computed the log posterior likelihoods per participant and found no significant difference between the diagnostic groups suggesting the goodness of fit was comparable across groups (t=-0.59, df=53.54, p>0.56).

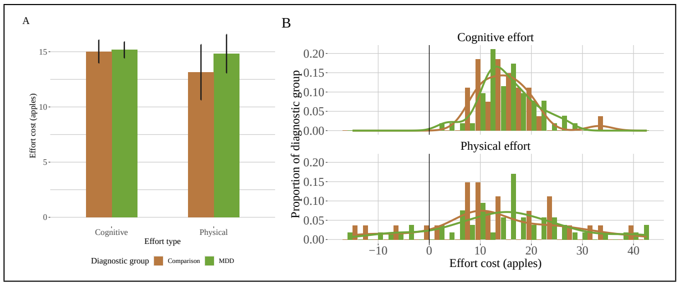

Figure 2: Effort cost by diagnostic group and effort type. Left panel: mean and standard error of the mean of individual differences in effort cost (y-axis) by effort type (x-axis). Right panel: individual differences histograms, x-axis indicates effort cost (larger values indicate more effort avoidance), y-axis indicates proportion of diagnostic group.

No diagnostic group differences in effort costs We predicted cognitive or physical effort costs by diagnostic group, controlling for high effort task performance, years of education, age, and BMI (for physical effort). There were no group differences in either effort cost (Figure 2, cognitive: p>0.66, physical: p>0.48), even when controlling for psychoactive medication status (cognitive: p>0.15, physical: p>0.31), and when excluding remitted MDD participants (cognitive: p>0.97, physical: p>0.60).

Symptom strength relationships to effort costs We fitted a series of regression models to estimate the relationships of symptom domains to cognitive and physical effort cost while controlling for high effort travel task performance, age, years of education, and BMI (for physical effort). Because of mutual correlations between symptoms, we used multiple comparisons correction within a series of symptom models (FDR, 7 tests). Anxiety was related to *decreased* cognitive effort cost (Figure 3, Table 1). Decreased cognitive effort cost was also associated with anhedonia, behavioral apathy, cognitive function symptoms, depressed mood/suicidality, and physical anergia/slowing in the MDD group. These results were maintained when controlling for psychoactive medication status.

Based on our inclusion of participants with comorbid anxiety disorders and on prior literature relating anxiety to increased effortful model-based strategy, we hypothesized that anxiety symptoms could be driving the overall depression association with cognitive effort cost. We tested whether any other symptoms were related to cognitive effort cost when controlling for anxiety and found no reliable relationships (although the behavioral apathy effect remained significant before, but not after, correcting for multiple comparisons, Table 1).

We next examined symptom associations with physical effort costs. Within the MDD group, anhedonia was associated with *increased* physical effort costs (Table 1). This effect was maintained when controlling for psychoactive medication status ($p<0.008$) though not after FDR correction ($p>0.056$). There was a significant difference in the magnitude of the correlation of cognitive and physical effort cost with anxiety (z=-2.47, p=0.014) and anhedonia (z=-3.25, p=0.001) within the MDD group.

Symptom	**Estimate**	**SE**	***t***	***p***	$p_{adjusted}$
A. Cognitive effort cost, MDD					
Overall depression	-0.31	0.10	-2.96	0.005*	
Anhedonia	-2.75	1.19	-2.32	0.025	0.035*
Anxiety	-3.72	0.97	-3.84	0.000	0.003*
Behavioral apathy	-3.92	1.28	-3.06	0.004	0.008*
Social apathy	-1.07	1.14	-0.94	0.351	0.351
Cognitive function symptoms	-2.10	0.97	-2.16	0.036	0.042*
Depressed mood/suicidality	-3.64	1.14	-3.19	0.003	0.008*
Physical anergia/slowing	-3.44	1.16	-2.96	0.005	0.008*
B. Physical effort cost, MDD					
Overall depression	0.15	0.27	0.58	0.565	
Anhedonia	8.38	2.90	2.89	0.006	0.042*
Anxiety	0.60	2.72	0.22	0.826	0.826
Behavioral apathy	7.59	3.25	2.33	0.024	0.084
Social apathy	1.76	2.76	0.64	0.527	0.615
Cognitive function symptoms	4.23	2.64	1.60	0.117	0.273
Depressed mood/suicidality	3.76	2.90	1.30	0.201	0.352
Physical anergia/slowing	2.95	3.24	0.91	0.368	0.515

Table 1: Symptom effort cost regressions (MDD group only). (A) Predicting cognitive effort cost from overall depression severity, and each symptom domain, controlling for cognitive task performance (3-Back D') years of education and age. (B) Predicting physical effort cost from overall depression severity, and each symptom domain, controlling for physical task performance (% larger number of presses completed), BMI, years of education and age.

Travel task performance We hypothesized that group and effects related to symptom strength related would be specific to effort cost and not accounted for by travel task ability. This confound was more of a concern for cognitive effort (versus physical which was individually calibrated). Across all of the travel task measures tested we found few reliable diagnostic group differences, including no difference in missed N-Back trials, cognitive task accuracy (D'), or required keypresses determined in the calibration phase. We found the MDD group completed a lower percent of required keypresses in the larger press condition (t=-3.52, df=3237, $p<0.001$), and responded faster on average on the cognitive (N-Back) task (t=-2.34, df=4955, $p<0.020$). We also found that effort costs are dissociable from ability in this task as cognitive task performance did not reliably predict cognitive effort cost (model 1: 3-Back D', t(76)=-1.25, p=0.22, 1-Back D' t(76)=-0.27, p=0.79, all participants, model 2: change D' t(76)=-0.63, p=0.53). Likewise the percent of key presses completed did not predict physical effort cost (Larger number of presses, t(77)=0.12, p=0.91, Smaller number of presses, t(77)=-1.28, p=0.20). While anxiety symptoms were associated with cognitive effort cost, they were not associated to cognitive task performance (MDD group predict by anxiety symptoms controlling for age by 3-Back D', $p>0.21$, 1-Back D', $p>0.79$). Likewise cognitive travel task performance was not related to overall depression (predict Hamilton Rating Scale Total controlling for age by 3-Back D',$p>0.16$, 1-Back D', $p>0.86$).

Discussion

Contrary to our hypotheses, we did not observe group differences in cognitive or physical effort costs, though this is consistent with some null diagnostic group results in previous studies of cognitive (Barch et al., 2023; Tran et al., 2021) and physical effort avoidance (Cathomas et al., 2021; Sherdell et al., 2012; Tran et al., 2021; Wang et al., 2022; X. Yang et al., 2021). There were also mostly no differences in travel task performance besides faster N-Back reaction times and lower percent required presses completed in the larger number of presses condition in the MDD group. Travel task performance and cognitive effort cost were not correlated in this sample, suggesting they are dissociable using this task.

Cognitive effort cost negatively related to anxiety

Surprisingly, we found that cognitive effort cost had a trending negative association with overall depression, such that more depressed participants in the MDD group were more willing to exert cognitive effort. Significant relationships between cognitive effort cost and overall depression strength have not been found in previous studies (Ang et al., 2023; Barch et al., 2023; Hershenberg et al., 2016; Tran et al., 2021; Vinckier et al., 2022). We leveraged both clinician-rated and self-report measures of a range of depression symptom domains to conduct detailed symptom analyses. We found anxiety was significantly related to decreased cognitive effort cost. This effect was specific to anxiety as no other symptom domain was related to cognitive effort cost controlling for anxiety. To our knowledge no effort based decision studies on MDD have reported decreased cognitive effort avoidance associated with anxiety. Unlike cognitive effort costs, cognitive task performance (3-Back D') did not relate to overall depression or anxiety symptoms.

The negative association between anxiety and cognitive effort cost is consistent with research showing increased model-based planning associated with anxiety in large online samples (Gillan et al., 2016; Hunter et al., 2018). One possible

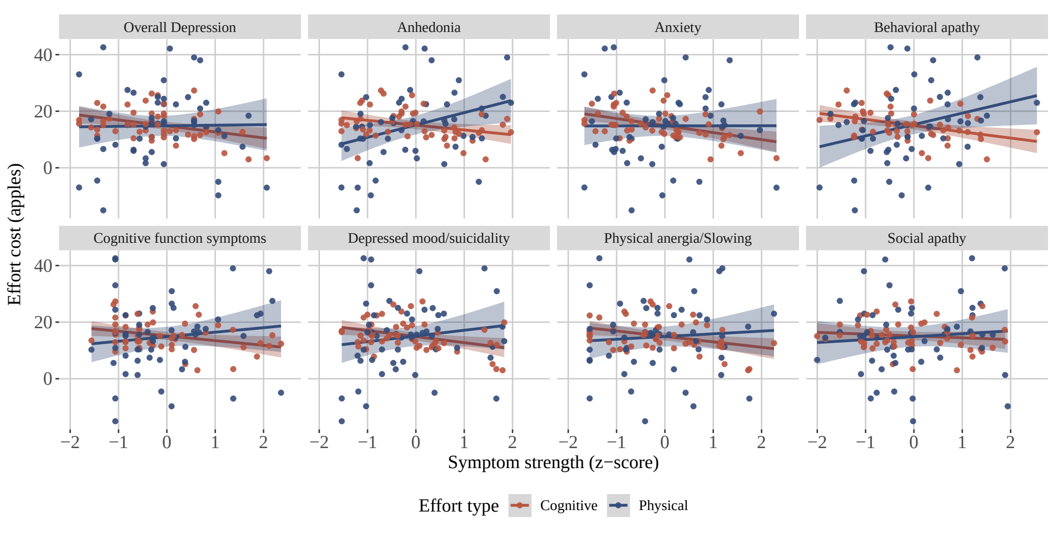

Figure 3: Effort costs relationships to individual MDD symptom domains. Blue indicates cognitive effort and red indicates physical effort. A: y-axes: effort costs from MVT model, x-axes: symptom severity (z-scores) for overall depression (Hamilton Rating Scale Total), anhedonia, anxiety, behavioral apathy, cognitive function symptoms, depressed mood/suicidality, physical anergia/slowing, and social apathy (MDD group only).

interpretation of the association of anxiety with cognitive effort cost is that increased willingness to exert cognitive effort may contribute to anxiety symptoms such as rumination and worry by increasing sampling for planning and replay (see Bedder et al., 2023). Another possibility is that higher cognitive effort tasks might have the benefit of increasing cognitive load and reducing anxious thoughts while completing the task. This is consistent with research showing reduced momentary anxiety during a high relative to low cognitive effort task (e.g., 3-Back versus 1-Back during an anxiety inducing task Vytal et al., 2012). The tendency to be more willing to exert cognitive effort could be leveraged as a strength in treatment for individuals with anxious depression (e.g., positive fantasizing, more cognitively effortful therapies Besten et al., 2023).

Physical effort cost positively related to anhedonia and behavioral apathy symptoms

We found a trend for physical effort cost to correlate positively with overall clinician rated depression. The absence of a significant relationship of physical effort avoidance to overall depression severity is consistent with some prior studies (Cathomas et al., 2021; Tran et al., 2021; X.-H. Yang et al., 2014), though some associations have been reported (Treadway, Buckholtz, et al., 2012; Zou et al., 2020). Anhedonia was significantly associated with increased physical effort cost, consistent with some previous reports (Sherdell et al., 2012; Tran et al., 2021; X.-H. Yang et al., 2014) but not others (Berwian et al., 2017; Cathomas et al., 2021; Cléry-Melin et al., 2011; Vinckier et al., 2022; Wang et al., 2022; X. Yang et al., 2021; Zou et al., 2020).

Limitations and future directions

Because of their distinctive relationships to symptom domains, these findings support the measurement of both cognitive and physical effort domains as a decision making function markers which may inform heterogeneity or subtypes of MDD. The presence of symptom relationships which have been mixed in other studies, might be because of theorized methodological improvements of the Effort Foraging Task, which was developed to measure effort preferences indirectly, so as to increase validity. Future work can also test whether these symptom relationships are generalizable across other effort based decision tasks. The present study leaves open the question of whether the observed symptom associations are specific to MDD or would be transdiagnostic. Another limitation of this study is the sample size. The smaller size of the comparison group may have contributed to the lack of observed diagnostic group differences. The small size of the remitted depressed group did not allow for comparing the remitted group to current depressed and comparison groups. Heterogeneity in use of psychoactive medication in MDD participants is another limitation of the study, given neurotransmitter effects on aspects of cognition measured in the task. However, controlling for psychoactive medication status did not change our findings. The cross sectional design is a limitation with respect to understanding causality between the symptoms and behavioral measures. Longitudinal investigations would help to distinguish state versus trait influences on cognitive control and effort-based decision making and their ability to predict symptoms. Ultimately insights from this research may be applied to interventions to increase willingness to exert effort, particularly for individuals who experience challenges engaging effort due to psychiatric disability.

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